Global calculation of beta-decay and accompanying processing the improved gross Theory

Hiroyuki KOURA
Advanced Science Research Center, Japan Atomic Energy Agency, JAPAN

Hiroyuki Koura and Satoshi Chiba, Phys. Rev. C **95**, 064304 (2017)

Introduction: Global properties of nuclei

Calculating ground-state nuclear masses:

KTUY (Koura-Tachibana-Uno-Yamada) mass model

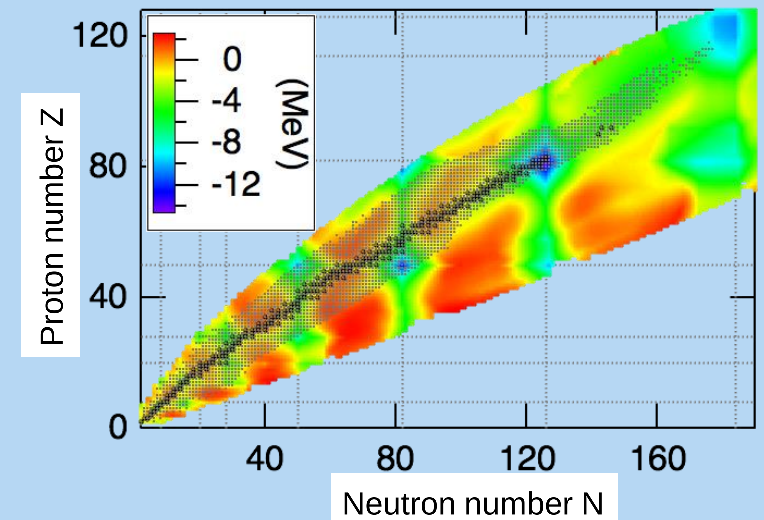
$$M(Z, N) = M_{gross}(Z, N) + M_{eo}(Z, N) + M_{shell}(Z, N)$$

$M_{shell}(Z, N)$ Spherical nuclei: modified Wood-Saxon pot.

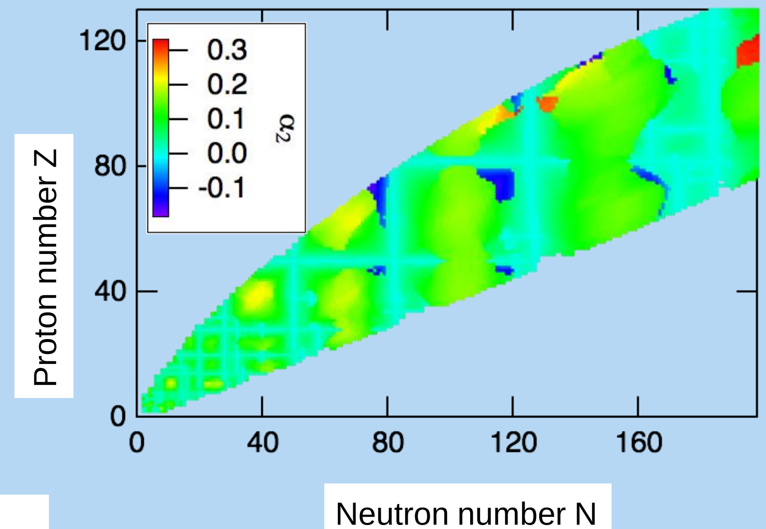
Deformed nuclei (Spherical-basis mathod)

Obtained by **an appropriate mixture** of the above spherical shell energies + liquid-drop deform. energies

(Koura, Uno, Tachibana, Yamada, NPA**674**, 2000)
(Koura, Tachibana, Uno, Yamada, PTP**113**, 305 2005)
(Koura. PTEP**2014**, 113D02, 2014)



Nuclear shell energy

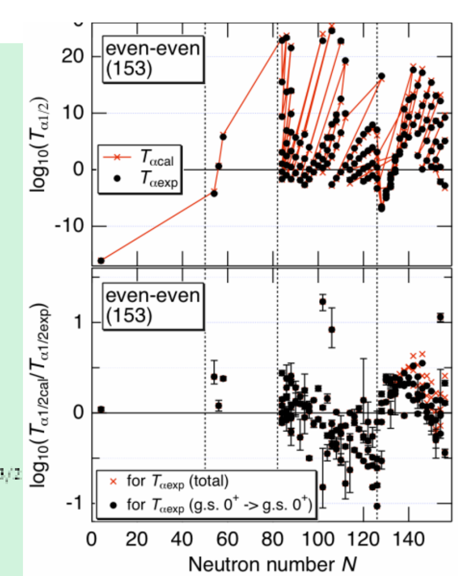


Deformation parameter α_2
(α_4 and α_6 are also calculated)

Calculating decay modes:

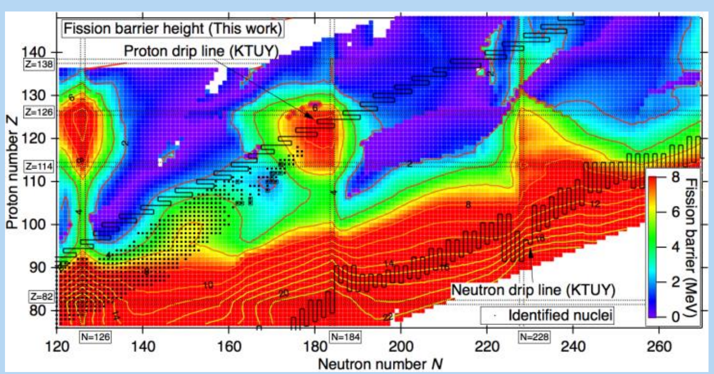
α-decay, β-decay, fission

$$\log_{10} T_\alpha(\mathrm{s}) = 1.7195\sqrt{\frac{A-4}{A}} Z_D / \sqrt{Q_\alpha(\mathrm{MeV})} - 1.2901\sqrt{\frac{A-4}{A}}\sqrt{RZ_D} + 0.07466\sqrt{\frac{A-4}{A}} R^{3/2}/Z_D^{1/2} \cdot Q_\alpha(\mathrm{MeV}) + 0.005499\sqrt{\frac{A-4}{A}} R^{5/2}/Z_D^{3/2} \cdot (Q_\alpha(\mathrm{MeV}))^{3/2} - \log_{10} N - 0.159175 + h,$$



Alpha-decay half-lives

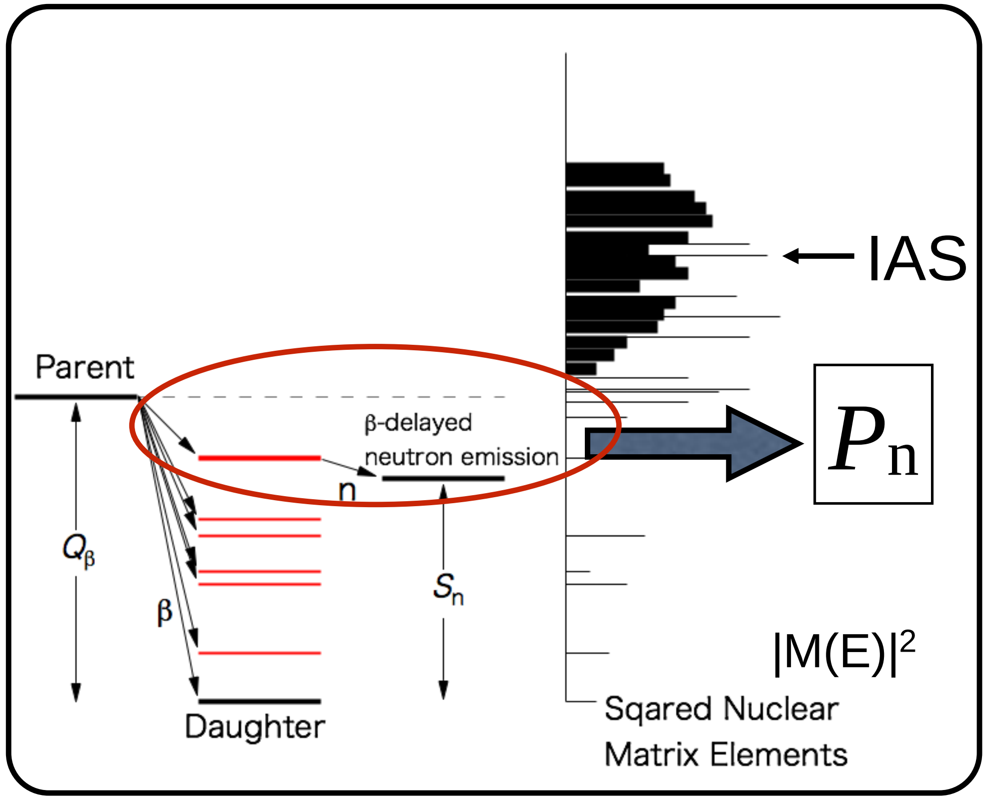
Alpha-decay: (Koura, JNST **49**, 816 (2012))
Fission: (Koura, AIP Conf.**4704,** 60 (2004))



Fission-barrier height

Nuclear β-decay and delayed neutron

Schematic view of beta-decay



Half-life

$$T_{1/2} = \frac{\ln 2}{\lambda}$$

$$\lambda = \lambda_F + \lambda_{GT} + \lambda_1^{(0)} + \lambda_1^{(1)} + \lambda_1^{(2)}$$ (up to 1st forbidden)

Decay constant

$$\lambda_F = \frac{m_e{}^5c^4}{2\pi^3\hbar^7}|g_V|^2\int_{-Q}^{0}|M_F(E)|^2 f(-E)dE$$

$$\lambda_{GT} = \frac{m_e{}^5c^4}{2\pi^3\hbar^7}|g_A|^2 3\int_{-Q}^{0}|M_{GT}(E)|^2 f(-E)dE$$

$$\lambda_1^{(2)} = \frac{m_e{}^5c^4}{2\pi^3\hbar^7}\left(\frac{m_e c}{\hbar}\right)^2|g_A|^2\int_{-Q}^{0}\sum_{ij}|M_{ij}(E)|^2 f_1(-E)dE$$ <-- unique 1st

$$\lambda_1^{(1)} = \frac{m_e{}^5c^4}{2\pi^3\hbar^7}\left(\frac{m_e c}{\hbar}\right)^2\left[|g_V|^2\int_{-Q}^{0}|M_{\boldsymbol{r}}(E)|^2 f_{1V}^{(1)}(-E)dE + |g_A|^2\int_{-Q}^{0}|M_{\boldsymbol{\sigma}\times\boldsymbol{r}}(E)|^2 f_{1A}^{(1)}(-E)dE\right]$$

$$\lambda_1^{(0)} = \frac{m_e{}^5c^4}{2\pi^3\hbar^7}\left(\frac{m_e c}{\hbar}\right)^2|g_A|^2\int_{-Q}^{0}|M_{\boldsymbol{\sigma}\cdot\boldsymbol{r}}(E)|^2 f_{1A}^{(0)}(-E)dE$$

M(E): Nuclear matrix elements
f(-E): Integrated Fermi function

Transition type

Trans.	Type	ΔL	Parity ch.
Allowed	Fermi	0	+
	Gamow-Teller	0,±1 (0 -×-> 0)	+
1st forbid.	non-unique 1st	0,±1	-
	unique 1st	±2	-
2nd forbid.	non-unique 2nd	±2	+
	unique 2nd	±3	+
3rd forbid.	non-unique 3rd	±3	-
	unique 3rd	±4	-

Delayed neutron probability

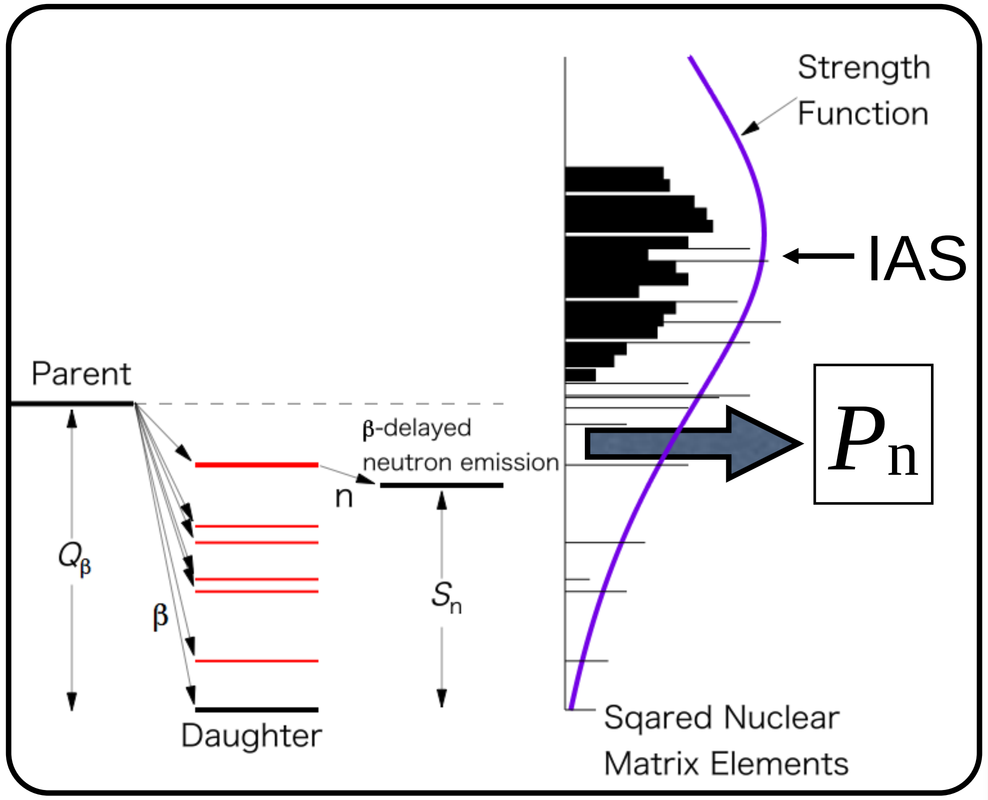
$$P_n = \frac{C}{\lambda_\beta}\int_{-Q_\beta+S_n}^{0}|M(E)|^2 f(Z,-E)\frac{\Gamma_n}{\Gamma_n+\Gamma_\gamma}dE$$

↑ decay competition

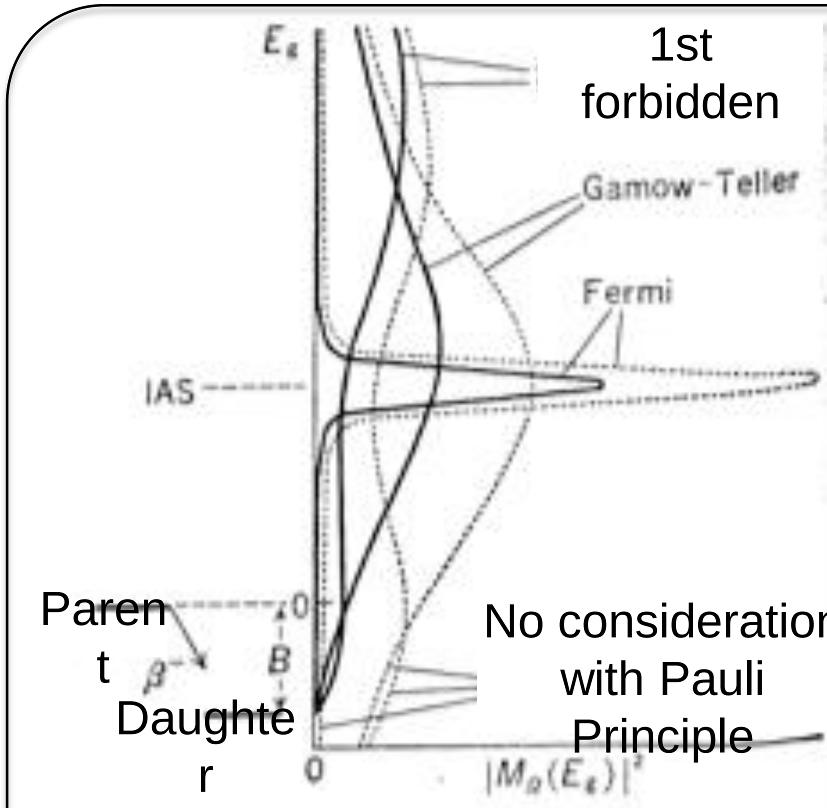
Delayed neutron is a phenomenon accompanied with the β decay.

Gross theory

Strength function of beta-decay



Overview of gross theory



$$|M_\Omega(E)|^2 = \int_{\epsilon_{min}}^{\epsilon_{max}} D(E,\epsilon) W(E,\epsilon) \frac{dn_1}{d\epsilon} d\epsilon$$

$D(E,\epsilon)$: one particle strength function

$\frac{dn_1}{d\varepsilon}$: level density

K. Takahashi et al., PTP 41(1969)→Concept
S. Koyama et al., PTP 44 (1970)→$dn_1/d\varepsilon$
K. Takahashi et al., ADNDT 12 (1973)→GT1
T. Kondoh et al., PTP 74 (1985)→BCS UV-factor
T. Tachibana et al.. PTP 84 (1990)→D(E,ε)
T. Tachibana et al., Proc. ENAM95 (1995)→GT2

Fermi, Gamow-Teller, and 1st forbidden can be calculated.

The gross theory includes:
1. Strength function (sum rules are considered)
2. BCS pairing (simply)
3. Forbidden transition
4. Fermi-gas level density (discrete treatment on the surface level))

Average treatment

Required sum rules

$$\int_{-\infty}^{\infty} D_F(E;\epsilon)dE = 1$$

$$\int_{-\infty}^{\infty} D_{GT}(E;\epsilon)dE = 3$$

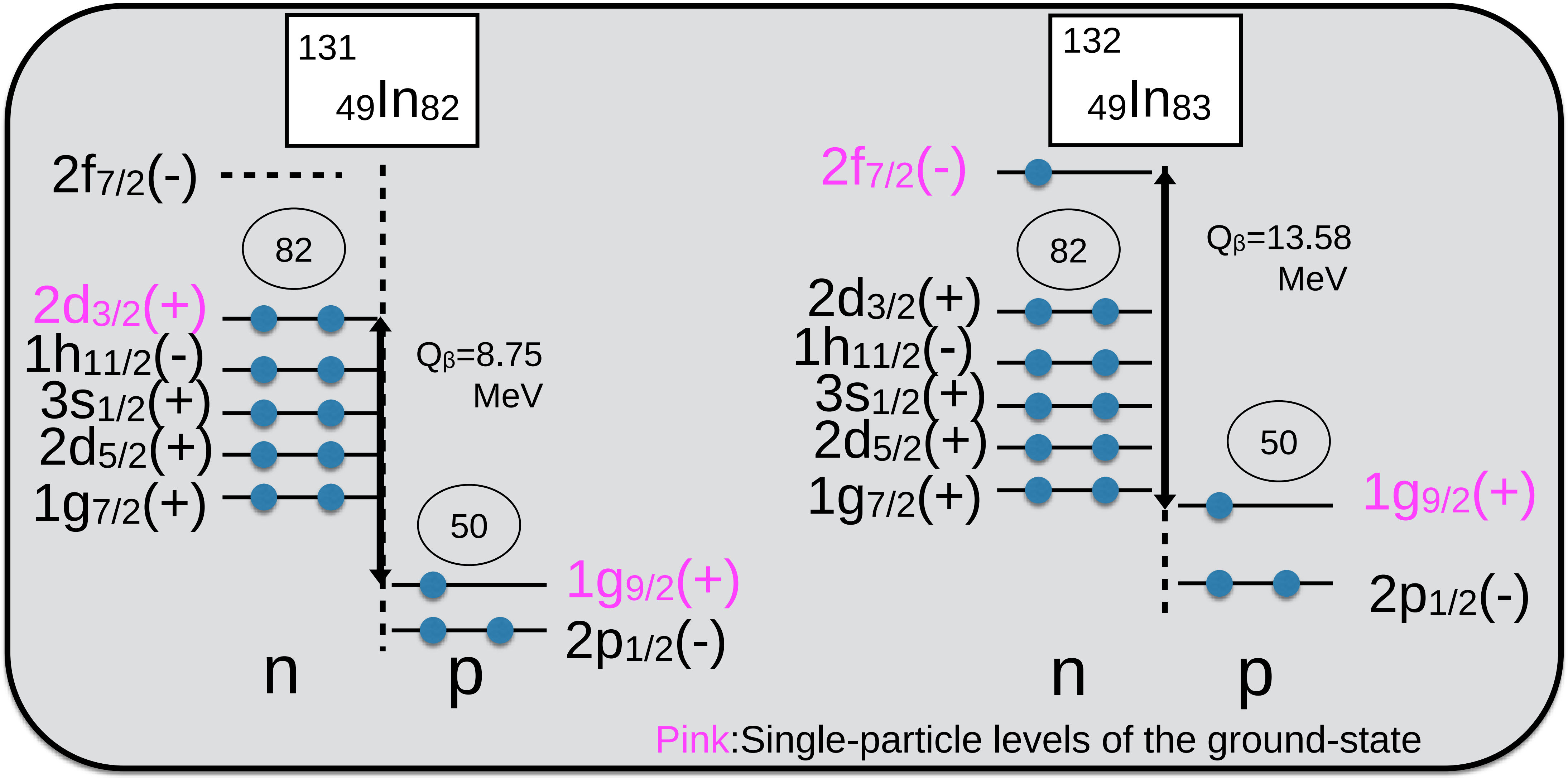
$$\int_{-\infty}^{\infty} D_r(E;\epsilon)dE = \langle r^2 \rangle \approx \frac{3}{5}R^2$$

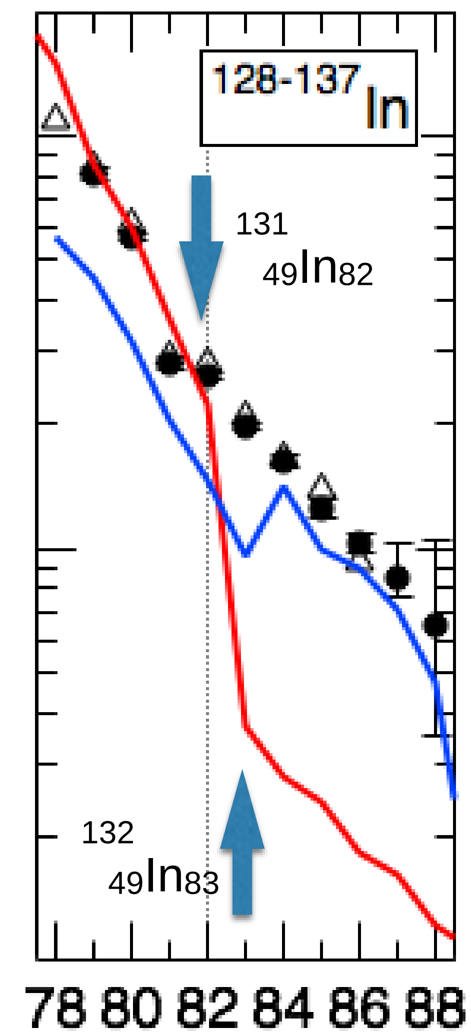
$$\frac{1}{3}\int_{-\infty}^{\infty} E D_{GT}(E;\epsilon)dE = \Delta E_C$$

$$\frac{1}{3}\int_{-\infty}^{\infty} E^2 D_{GT}(E;\epsilon)dE = (\Delta E_C)^2 + \sigma_C^2 + \sigma_N^2$$

H.K.,S. Chiba, Energy Procedia 71, 228 (2015)

Single-particle level

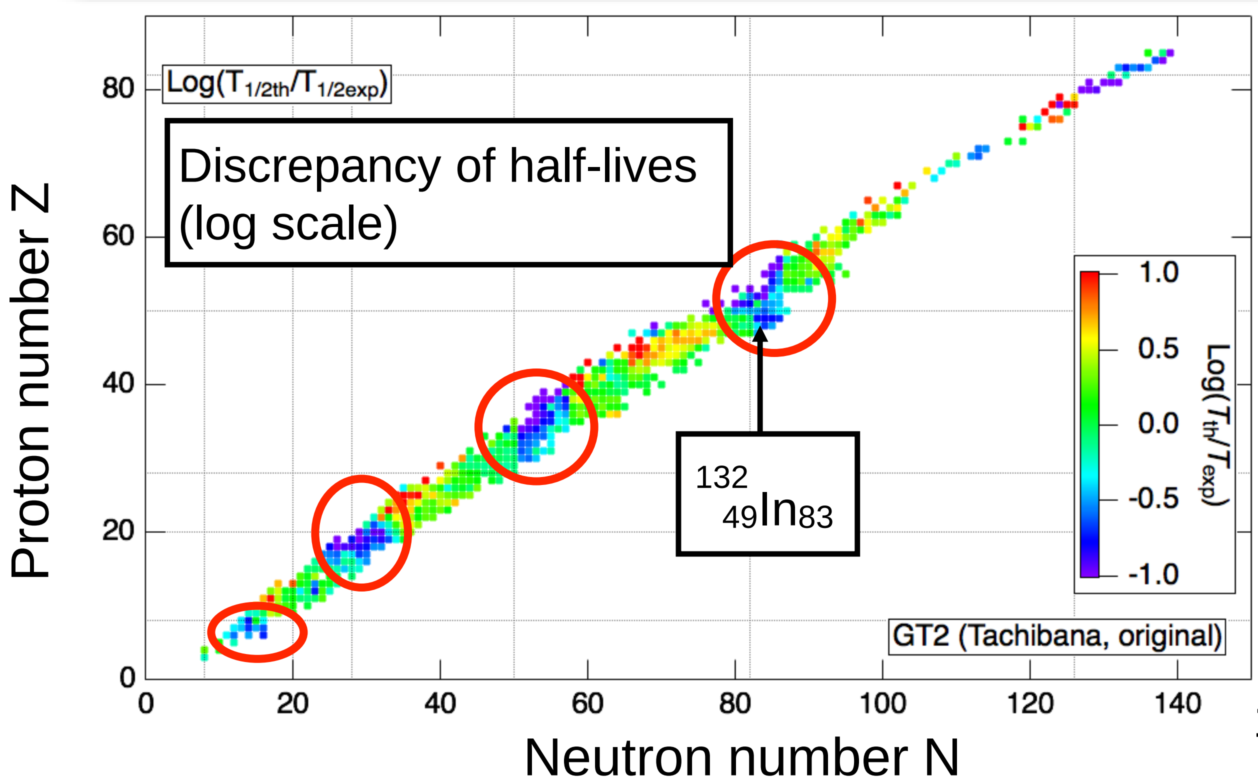




Red : KTUY+GT2	
Blue : FRDM+QRPA	

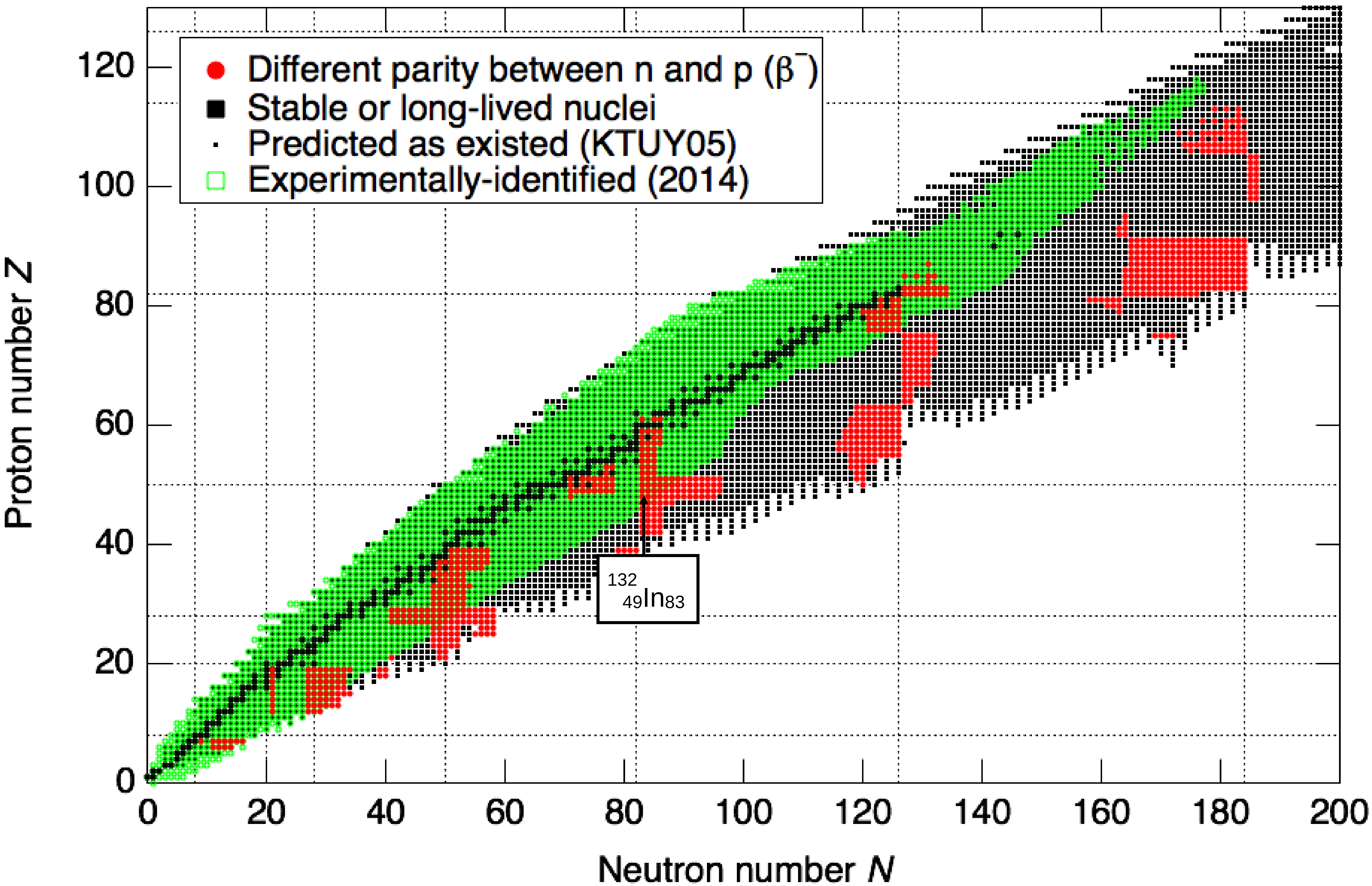
G. Lorusso et al., PRL114 (2015)

Measurement at RIKEN



Parity change of the ground-state levels(+→- or -→+) occurs.

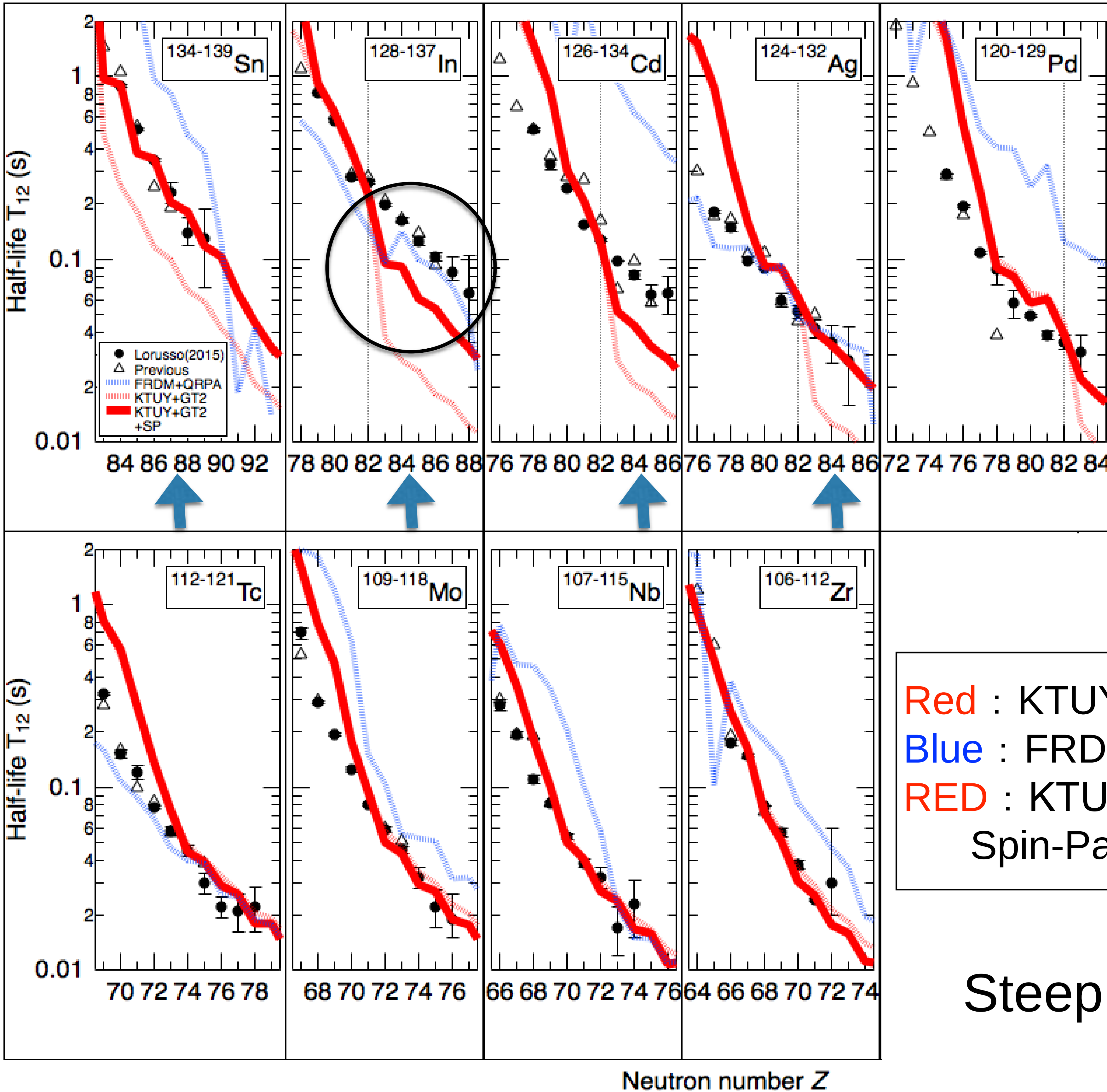
Region of parity-mismatching

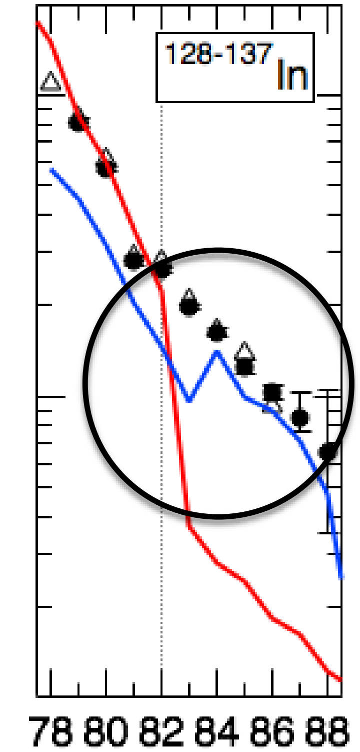


threshold of α_2=0.05

Results

1 :Half-lives (Local)





G. Lorusso et al.,
PRL114 (2015)

Measurement at RIKEN

Red : KTUY+GT2
Blue : FRDM+QRPA
RED : KTUY+GT2'
Spin-Parity

Steep changes at N=82 disappear.

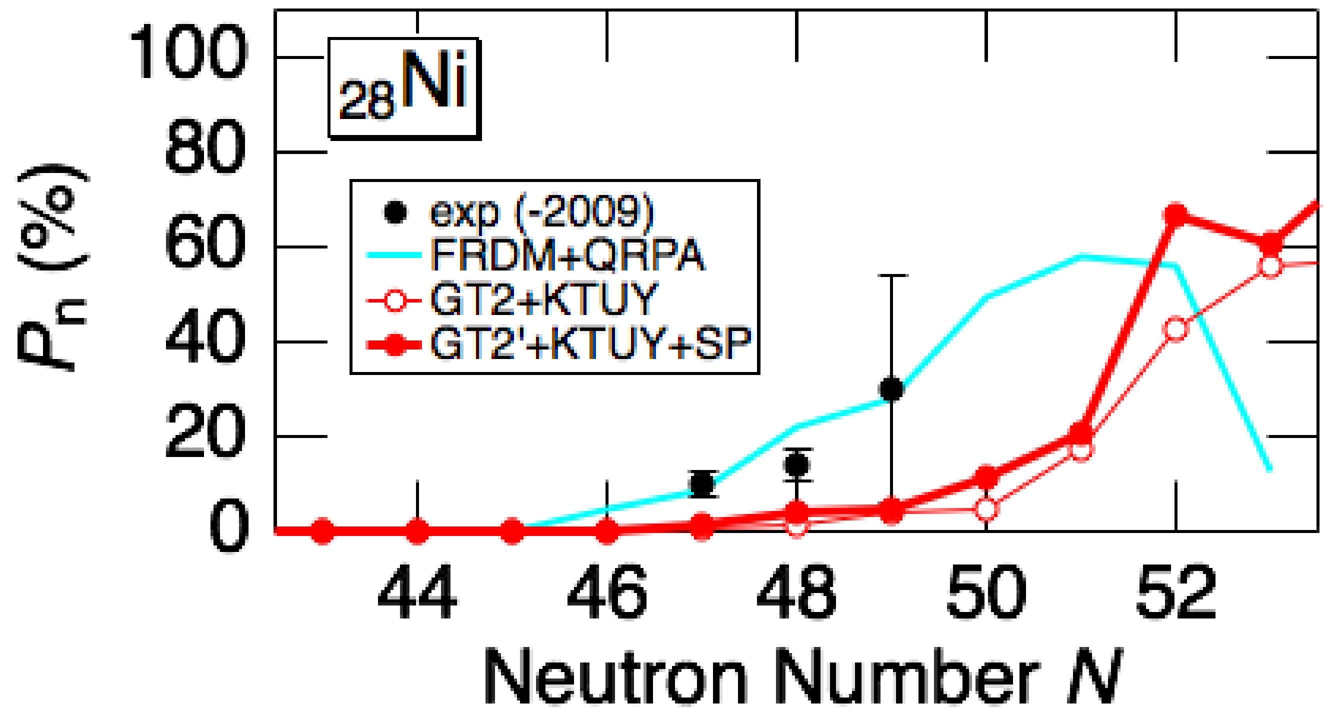
Results

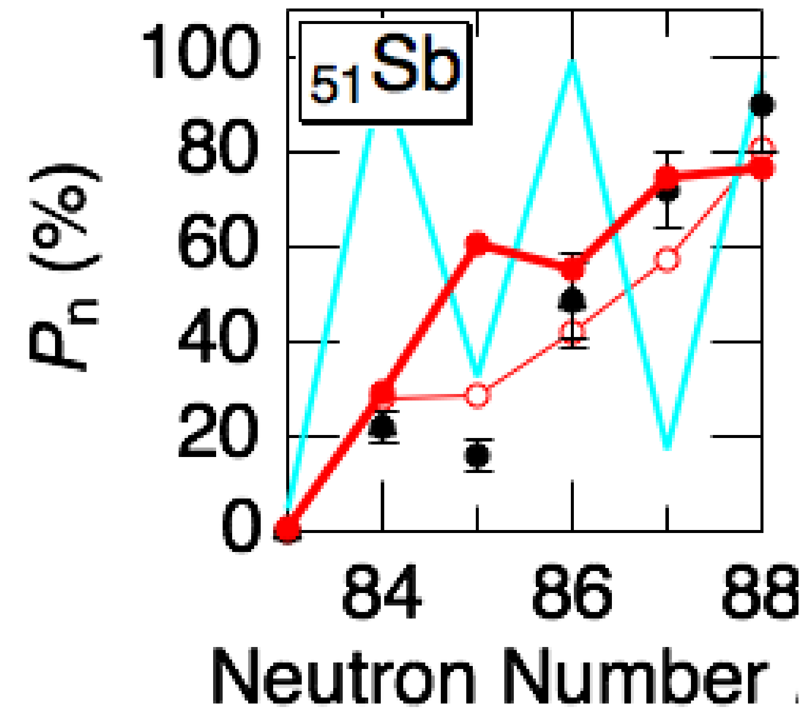
3:Delayed neutron probabilities

$$P_n = \frac{C}{\lambda_\beta}\int_{-Q_\beta+S_n}^{0} |M(E)|^2 f(Z,-E)\underline{\frac{\Gamma_n}{\Gamma_n+\Gamma_\gamma}}\, dE$$

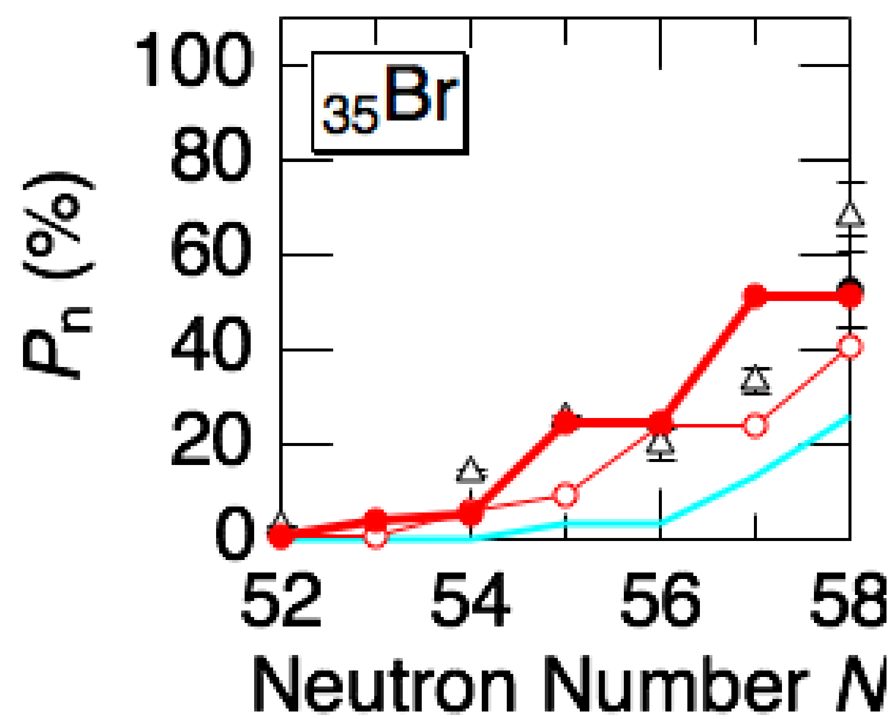
→ Unity

Neighboring Doubly-Magic





Dominant for fission from actinides

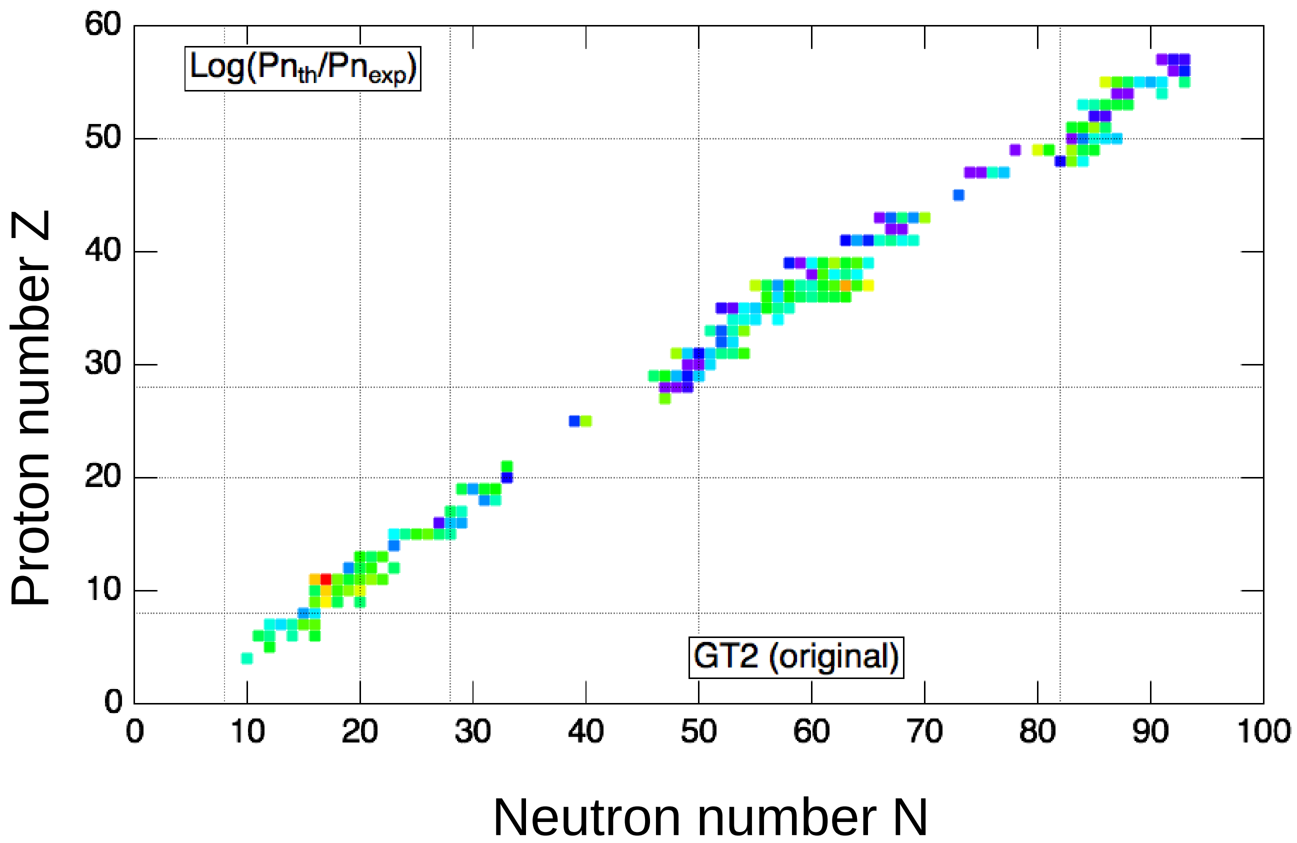


Results

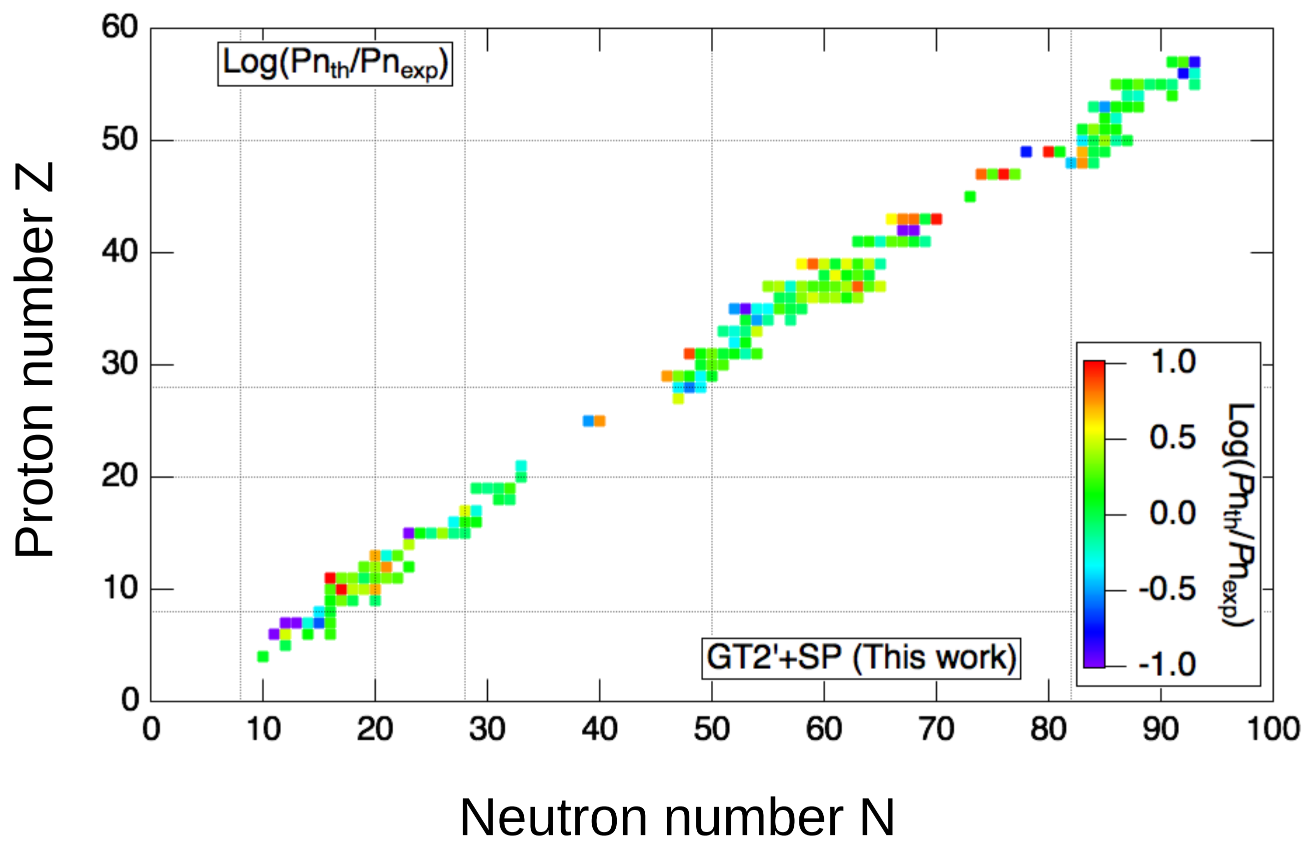
3:Delayed neutron probabilities

P_{nth}/P_{nexp} (in log scale)

Previous



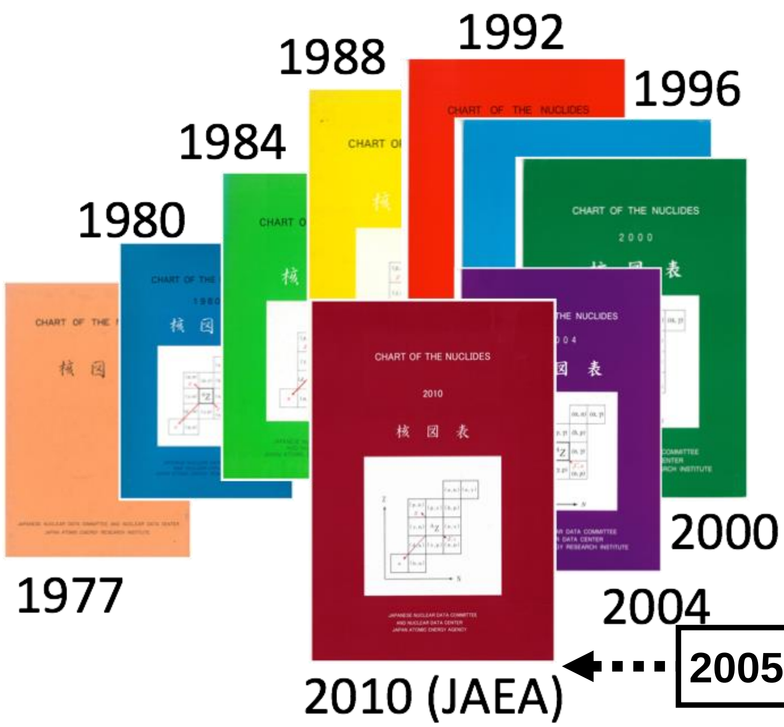
This work



RMS dev. 0.46(GT2)→0.46(this work)

Trends is somewhat different, but RMS is almost the same

Construction of “JAEA Chart of the Nuclides 2014”



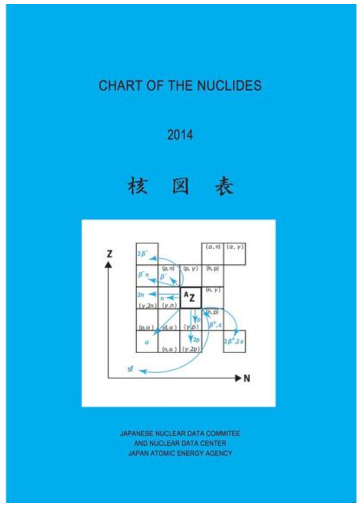
2005: JAERI to JAEA

Compilers:
Y. Yoshizawa (1977 - 1988)
T. Horiguchi (1977 - 2004)
M. Yamada (1977 - 1988)
T. Tamura (1992)
J. Katakura (1992 -)
T. Tachibana (1992 -)
H. Koura (2000 -)
F. Minato

Person: current compiler

Mar. 12, 2015

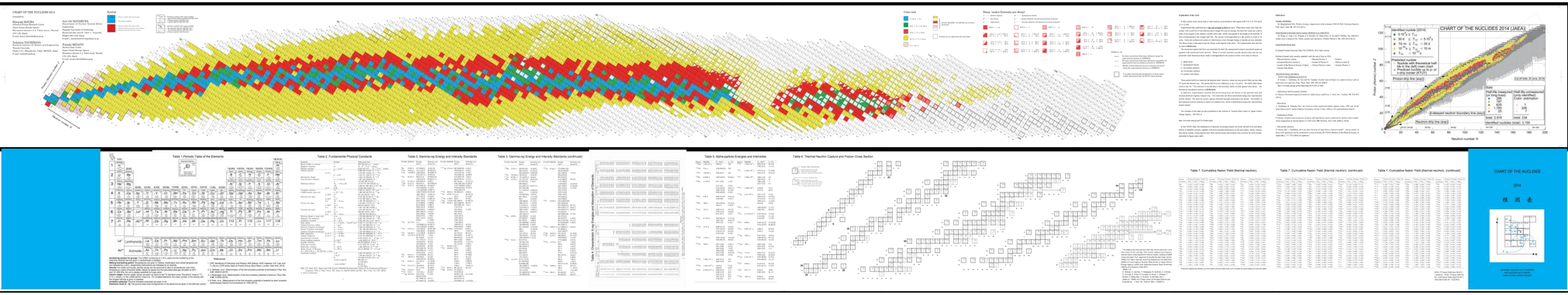
2014 (JAEA)



URL:http://wwwndc.jaea.go.jp/CN14/index.html

(the 10th revision)

12 pages | 4 pages (Newly added)



- A folding A4-size nuclear chart (16 pages X 2)
- **Theoretical half-lives for half-life-unmeasured nuclides** (Gross theory for beta-decay) ← **Unique**

CHART OF THE NUCLIDES 2014

Compiled by

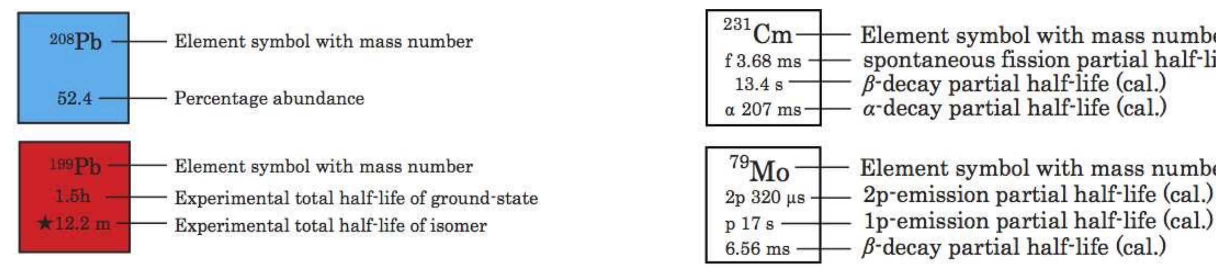
Hiroyuki KOURA
Advanced Science Research Center
Japan Atomic Energy Agency
Shirakata-shirane 2-4, Tokai-mura, Ibaraki
319-1195, Japan
E-mail: koura.hiroyuki@jaea.go.jp

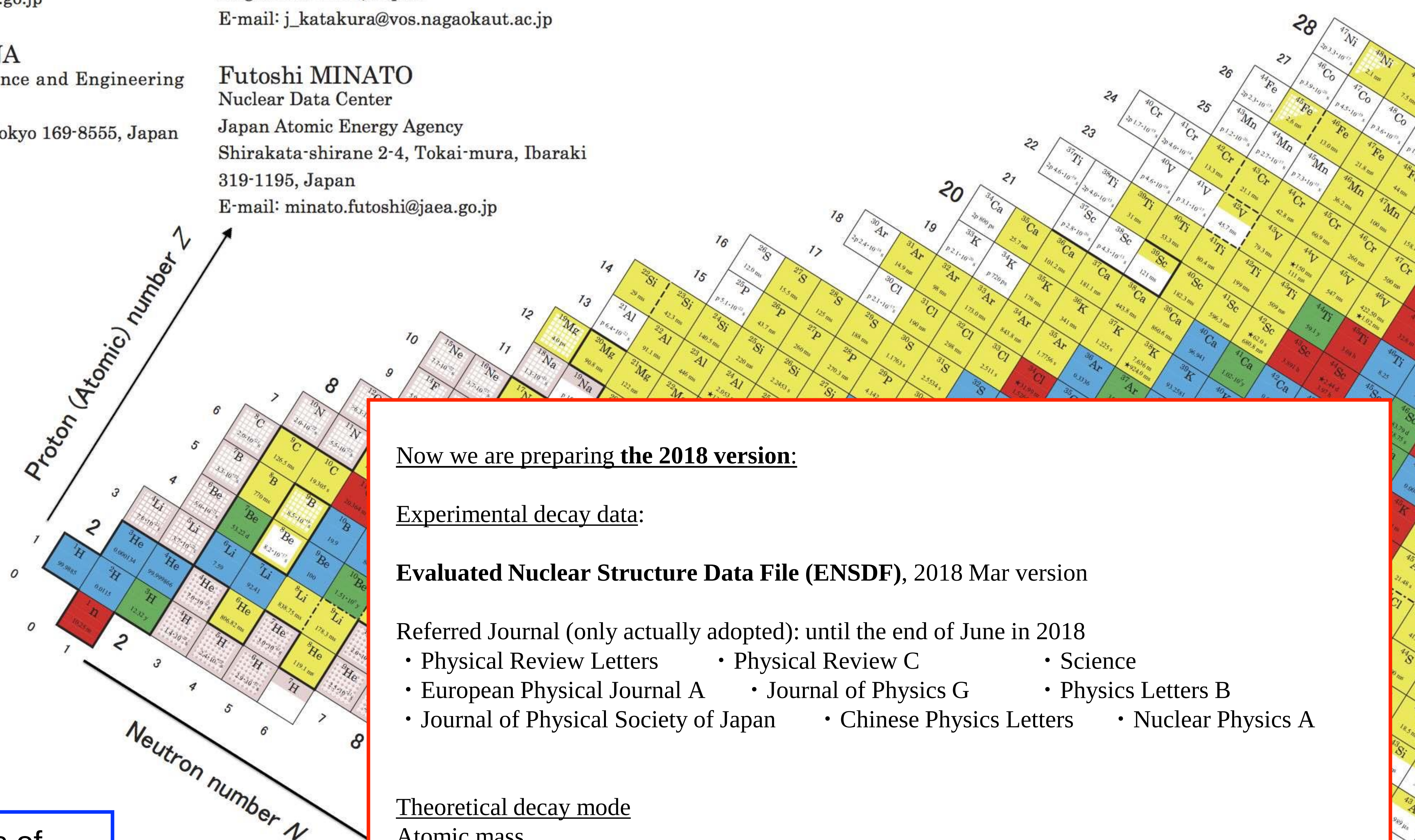
Jun-ichi KATAKURA
Department of Nuclear System Safety Engineering
Nagaoka University of Technology
Kamitomioka-machi 1603-1, Nagaoka, Niigata 940-2188, Japan
E-mail: j_katakura@vos.nagaokaut.ac.jp

Takahiro TACHIBANA
Research Institute for Science and Engineering
Waseda University
Okubo 3-4-1, Shinjuku-ku, Tokyo 169-8555, Japan
E-mail: ttachi@waseda.jp

Futoshi MINATO
Nuclear Data Center
Japan Atomic Energy Agency
Shirakata-shirane 2-4, Tokai-mura, Ibaraki
319-1195, Japan
E-mail: minato.futoshi@jaea.go.jp

Symbol





Now we are preparing **the 2018 version**:

Experimental decay data:

Evaluated Nuclear Structure Data File (ENSDF), 2018 Mar version

Referred Journal (only actually adopted): until the end of June in 2018

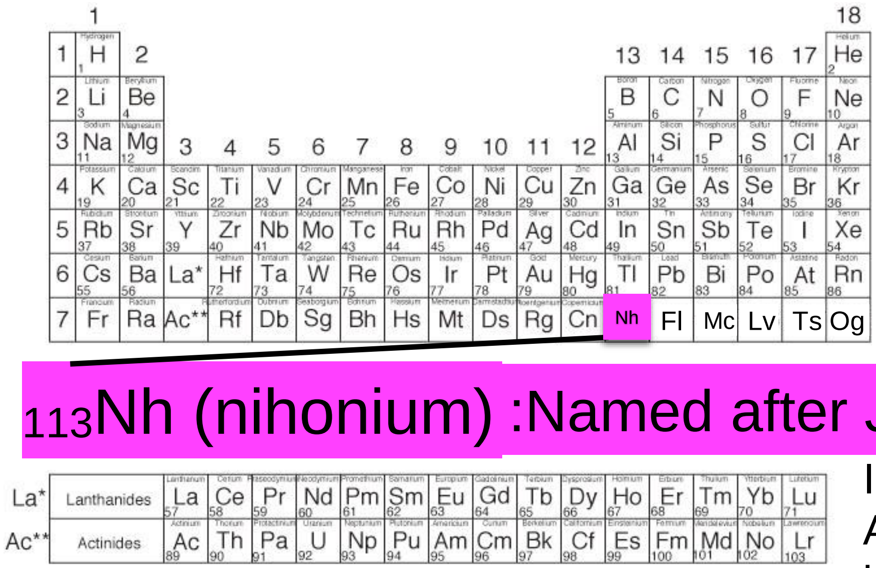
・Physical Review Letters ・Physical Review C ・Science
・European Physical Journal A ・Journal of Physics G ・Physics Letters B
・Journal of Physical Society of Japan ・Chinese Physics Letters ・Nuclear Physics A

Theoretical decay mode
Atomic mass
H. Koura, *et al.*, Prog. Theor. Phys. **113**, 305-325 (2005)
http://wwwndc.jaea.go.jp/nucldata/mass/KTUY04_E.html

Half-lives, decay modes of ground-states and some timers are adopted from **ENSDF** and recent referred papers.

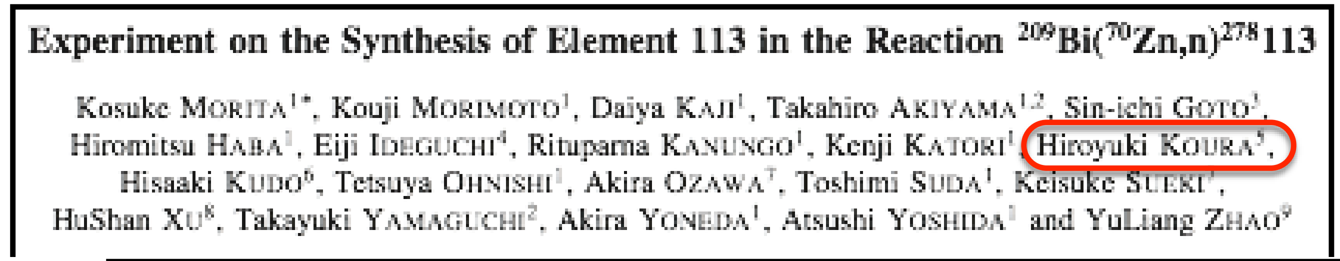
Other topics

Superheavy element



$_{113}$Nh (nihonium) :Named after Japan

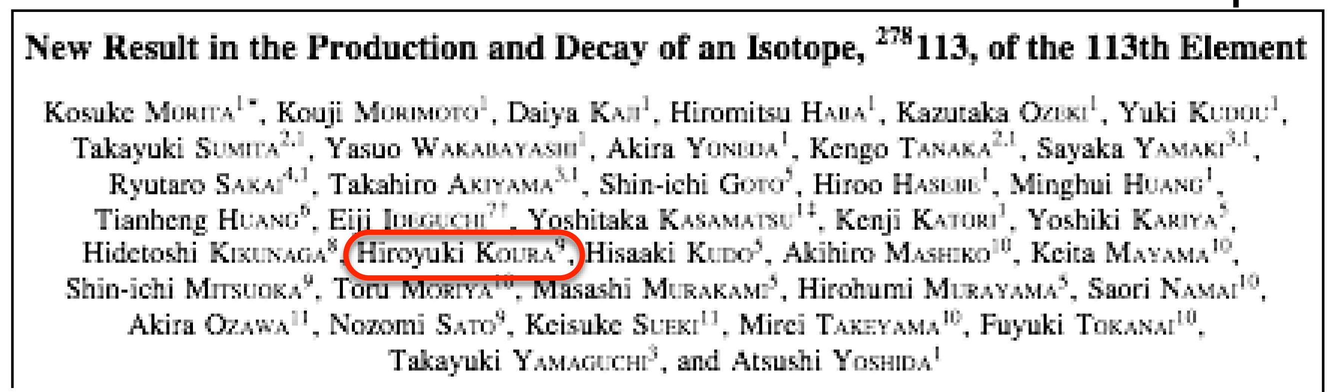
In 2016 Approved by IUPAC



Experiment on the Synthesis of Element 113 in the Reaction ^{209}Bi(^{70}Zn,n)^{278}113

Kosuke MORITA[1*], Kouji MORIMOTO[1], Daiya KAJI[1], Takahiro AKIYAMA[1,2], Sin-ichi GOTO[3], Hiromitsu HABA[1], Eiji IDEGUCHI[4], Rituparna KANUNGO[1], Kenji KATORI[1], Hiroyuki KOURA[5], Hisaaki KUDO[6], Tetsuya OHNISHI[1], Akira OZAWA[7], Toshimi SUDA[1], Keisuke SUEKI[7], HuShan XU[8], Takayuki YAMAGUCHI[2], Akira YONEDA[1], Atsushi YOSHIDA[1] and YuLiang ZHAO[9]

JPSJ, **73** (2004)



New Result in the Production and Decay of an Isotope, ^{278}113, of the 113th Element

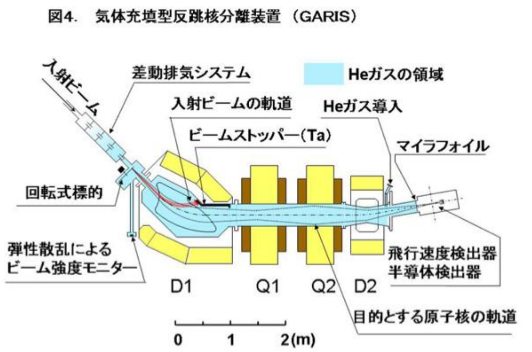
Kosuke MORITA[1*], Kouji MORIMOTO[1], Daiya KAJI[1], Hiromitsu HABA[1], Kazutaka OZEKI[1], Yuki KUDOU[1], Takayuki SUMITA[2,1], Yasuo WAKABAYASHI[1], Akira YONEDA[1], Kengo TANAKA[2,1], Sayaka YAMAKI[3,1], Ryutaro SAKAI[4,1], Takahiro AKIYAMA[3,1], Shin-ichi GOTO[5], Hiroo HASEBE[1], Minghui HUANG[1], Tianheng HUANG[6], Eiji IDEGUCHI[7], Yoshitaka KASAMATSU[1,‡], Kenji KATORI[1], Yoshiki KARIYA[5], Hidetoshi KIKUNAGA[8], Hiroyuki KOURA[9], Hisaaki KUDO[5], Akihiro MASHIKO[10], Keita MAYAMA[10], Shin-ichi MITSUOKA[9], Toru MORIYA[10], Masashi MURAKAMI[5], Hirohumi MURAYAMA[5], Saori NAMAI[10], Akira OZAWA[11], Nozomi SATO[9], Keisuke SUEKI[11], Mirei TAKEYAMA[10], Fuyuki TOKANAI[10], Takayuki YAMAGUCHI[3], and Atsushi YOSHIDA[1]

JPSJ, **81** (2012)

”日本”: **nippon** or **nihon**

***'Japan' is introduced through Marco Polo (Italian,13-134) as 'Zipang'**

Naming ceremony with the crown prince of Japan at the Japan Academy on Mar. 2017.



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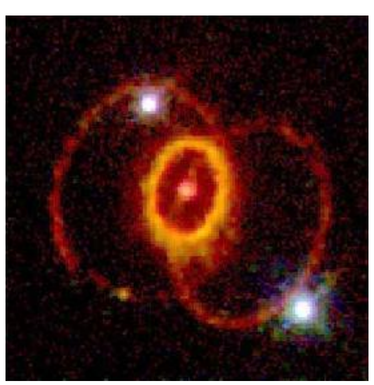
Nucleosynthesis in star



Remnant of supernova

The element of uranium is considered to be synthesized only by the rapid neutron capture process (r-process).